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Wind power in China—Opportunity goes with challenge

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ABSTRACT

Climate change and limited primary energy resources require indigenous renewable electricity generation options to change the current coal-dominated power source matrix in China. The wind power is such a solution for the above challenges, and it still has large space for improvement in China. In this paper several critical factors related to Chinese wind power were studied in details, including the wind resources, the wind turbine industry and the policies from the Chinese government. Based on the study, the perspective of wind power in China was discussed. With outstanding advantages, the offshore wind power has a bright future in China, so its main characteristics are discussed. Based on the discussions, suggestions were given to improve the development of Chinese wind power, and the government's further measures are also recommended.

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1. Introduction

1.1. China's challenge of energy and environment

The limited fossil energy resource is a critical issue worldwide. However, energy shortage is more serious in China compared with many other countries in the world. China occupies the 14th proved reserve in the world for both petroleum and natural gas, and its coal reserve is relatively large, just behind the United States and Russian Federation [1]. However, taking into account the largest population of 1.345 billion in the world, the Chinese per capita fossil reserves belong to a low level in the world. The Chinese per capita coal resource is 70.4% of the global average, while petroleum and natural gas just 6.2% and 6.8%, respectively [1,2].

The world witnessed a strongest periods of economic growth ever recorded until the middle of 2008, and this had continued to support global energy consumption. Although world primary energy consumption growth slowed to 2.4% in 2007 compared with that of 2.7% in 2006, it was still above the 10-year average for the fifth consecutive year. Due to the rapid economic development, China itself accounted for majority of the global energy consumption growth, with energy consumption rose by 8.4% and 7.7% in 2006 and 2007, respectively [3].

The financial crisis in September 2008 caused a sharp recession, and world primary energy consumption grew by just 1.4%, the slowest since 2001. Chinese consumption growth maintained a high level of 7.4%, accounting for nearly three-quarters of global growth. In the first quarter of 2009, China is still the key driver for the global energy supply, and there is no sign of changing for this in the near future.

Due to the enormous production and consumption, even the coal, with the richest reservation in Chinese primary energy resources, has a Reserve/Production ratio of just 81 years, two-thirds of the global level [1].

Environmental problem is another critical issue the China government has to face. The Chinese energy sector is coal-dominant, this not only has burdened Chinese energy supply seriously, but also has led to many environmental negatives, especially the climate change, which is the most highlighted global issue nowadays. Since 2006 China has surpassed the America and become the first CO_2 emitter in the world, with approximately 8% higher emissions than that of the USA [4]. Moreover, the still low per capita CO_2 emission of 2.9 t compared with that of America, Germany and Japan of 19.68, 10.35 and 9.41 t, respectively [5], makes a large climbing up of the total Chinese CO_2 emission inevitable in the future. The Chinese government has to take actions to change the current coal-dominated energy matrix, to reach a sustainable and environment friendly way of development.

1.2. Opportunity of the wind power in China

The only way to mitigate the energy and environmental problems is to utilize the renewable energies, including hydraulic power, wind power, biomass, solar heat and power, etc.

China is currently in the 11th five-year period (2006–2010) for economic and social development, with renewable energy as an important part. The targets until 2010 and 2020 are stipulated in the Mid-Long term Development Plan for Renewable Energy.

Table 1 lists the installed capacity by the end of the l0th five-year period (2001–2005) for various renewable sources as well as the targets in 2010 and 2020 [6,7]. The target of 2010 from all the renewable energy resources is 300 million tons of coal equivalent in total, or approximately 10% of China's total primary energy consumption at that time; in 2020 the capacity should be doubled, or reach 600 million tons of coal equivalent or 15% of the total, two times higher than the proportion of 7.5% in 2005.

It is obvious that wind power occupies an important position in the future Chinese power matrix as well as the energy construction. Wind power is the renewable energy power source only next to the hydropower, and it has the advantage of resource distribution characteristics.

1.3. The distribution characteristics of energy resources in China

The economic growth of various regions of China is quite different. Basically the eastern part, especially the littoral regions, is much more advanced than the middle and western part. The first 4 provinces with the largest economy scale, Guangdong, Shandong, Jiangsu and Zhejiang, are all located by the seashore, so does the richest city-Shanghai. However, the primary energy resources including the hydro-energy are scarce in these regions, while the energy consumption is large.

The most economical way to mitigate this contradiction is to develop the indigenous energy in the eastern regions, and the wind power can play an extremely important part in the local energy construction due to the excellent wind resources in littoral regions (Fig. 1).

2. Wind resources assessment for China

On a large scale, the latitude and physical geography including the proportion of land and sea, size of landmasses, presence of mountains or plains, altogether determine the wind resources distribution. More locally, the topography has a major effect on the wind climate [8].

China is located in the eastern part of Asia and the Pacific in the West Bank. Its land area is about 9.6 million km^2. China occupies the geographical zone of the latitude between 4° N and 53°30′ N and the longitude between 73°40′ and 135°05′. The topography varies greatly in China, with hilly land, plateaus, basins, rolling land and plains taking up the land proportion of 33.3%, 26%, 18.8%, 9.9% and 12.0%, respectively [9].

Abundant wind resources are mainly distributed in two areas in China, one of them is the so-called three-north (northeast, north and northwest) region, especially in the Inner Mongolia Autonomous Region. Generally the resource potential is above the level of moderate (class 3), with wind power density above 400 W/m^2, wind speed more than 6.4 m/s. Sites of good or excellent resource potential, with the wind power density above 400 W/m^2 or even reach 800 W/m^2, and wind speed more than 7.0 m/s, are suitable candidates to locate the wind power plants (Fig. 1).

Another area is located along the eastern seashore, with wind power above class 5. The resource potential in Shanghai, Zhejiang Province, Fujian Province and Circum-Bohai-Sea Region (Tianjin, Liaoning Province and Shandong Province) is excellent, wind power density of which above 500 W/m^2, wind speed more than 7.5 m/s. Thus it is easy to select sites to build onshore and offshore wind farms in this area. This area makes great sense because the electricity requirement is the largest in this richest region in China.

3. Wind turbine technology introduction

3.1. Introduction to wind turbine aerodynamics

Wind turbine is a device extracting kinetic energy from the wind [8]. Item exposed to wind is subjected to drag force parallel to the air flow as well as lift force perpendicular to the air flow. The earliest windmills used the drag on the blades to produce power, but the modern wind turbine is incorporated with the airflow of shapes of high lift and low drag. Wind turbine uses the lift on generated by the blade to produce power. Lift-type machines have

Table 1
2005 installed renewable energy capacity/production and targets in 2010 and 2020.

Source of renewable energy	2005 installed capacity	2010 target	2020 target
Hydropower (GW)	117, with 7 pumped storage	190	300
Wind power (GW)	1.31, with 50 MW off-grid	10	30
Solar PV (GW)	0.07	0.3	1.8
Biomass power (GW)	2	5.5	30
Biogas (m^3)	8 billion	19 billion	44 billion
Solar water heater (m^2)	80 million	150 million	300 million
Geothermal energy (tons of coal equivalent)	2 million	4 million	12 million
Bioethanol and Biodiesel (tons)	1.07 million, with 1.02 million bioethanol	3.3 million, with 3 million bioethanol	12 million, with 10 million bioethanol
Total (tons of coal equivalent)	166 million	300 million	600 million

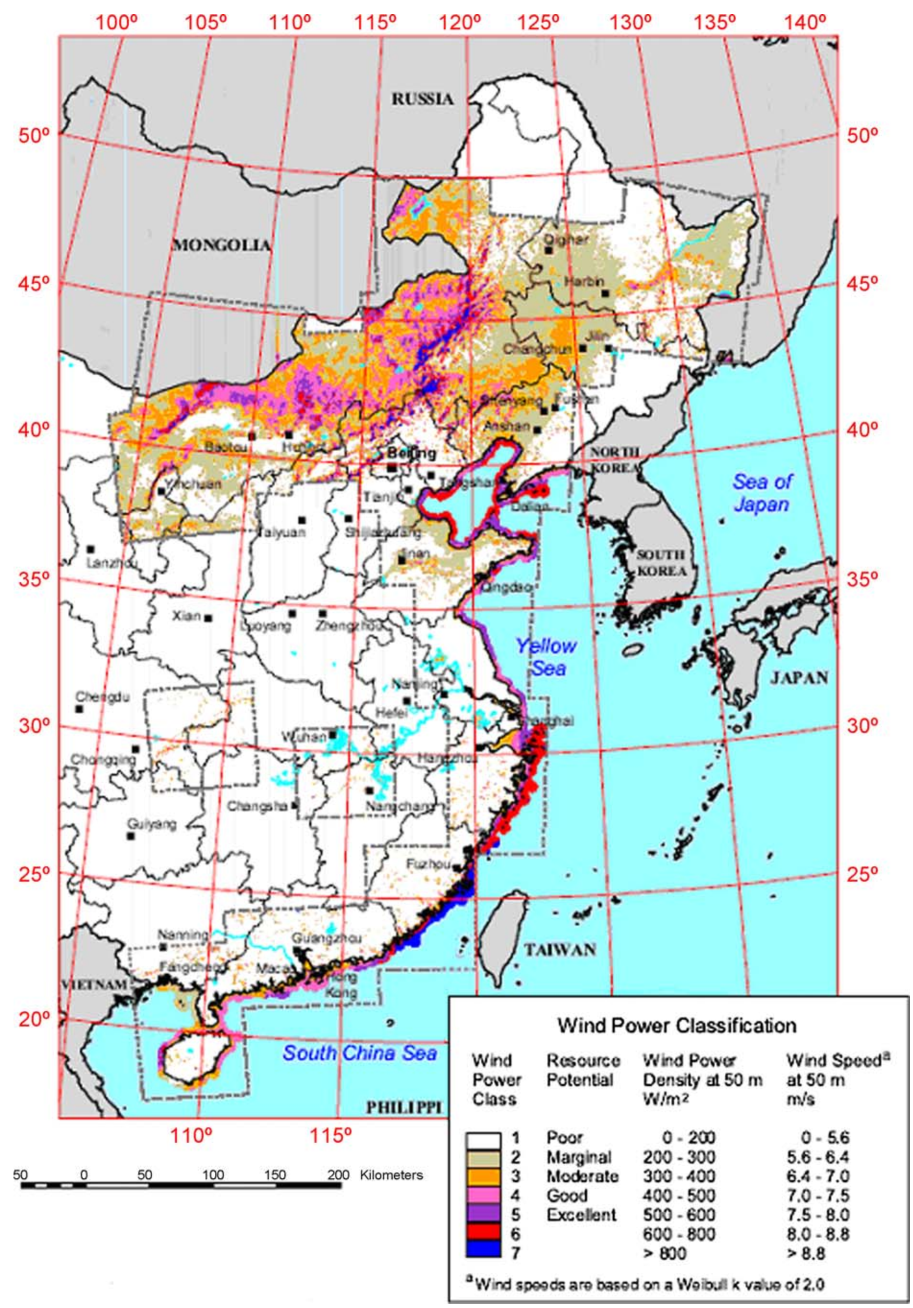

Fig. 1. 50 m wind map for east China (*source*: NREL).

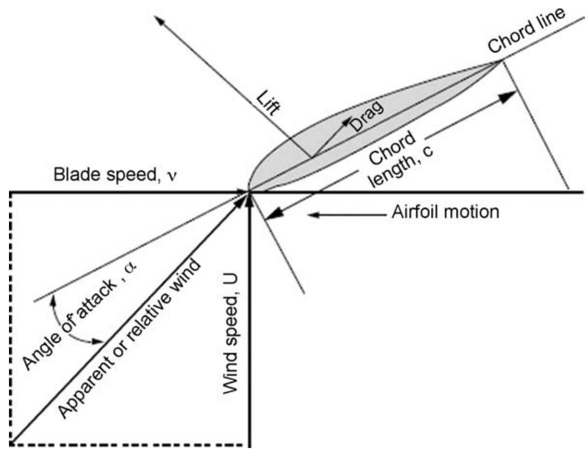

Fig. 2. Schematic of translating lift device.

a small number of blades because the blades must be widely separated to generate the maximum amount of lift [10].

Fig. 2 illustrates the translating lift device. The power extracted by this device can be expressed as

$$P = \frac{1}{2}\rho U^3 cl \frac{\nu}{U}\left(C_L - C_D \frac{\nu}{U}\right)\sqrt{1 + \left(\frac{\nu}{U}\right)^2} \quad (1)$$

where ρ is the air density, U the vector sum of the wind velocity, c the chord length, l the length of device in the span direction, ν the blade velocity, and C_L, C_D can be expressed as,

$$C_L = \frac{U_{\text{Lift}}}{1/2\rho c l U^2} \quad (2)$$

$$C_D = \frac{U_{\text{Drag}}}{1/2\rho c l U^2} \quad (3)$$

where U_{Lift} and U_{Drag} are the lift and drag coefficients, a function of airfoil shape and the angle of attack, α, respectively [11,12].

A well-designed lift-type machine can achieve a peak power coefficient of 0.5–0.59, while a pure drag-type machine can achieve a peak power coefficient of <0.2; in the other hand, the drag machines rotate slowly and produce high torque, whereas the lift machines rotate quickly and produce low torque. Extensive experience has shown that fast-rotating, lift-type machines are much easier to adapt to electrical generators and can produce electricity at a significantly lower COE than drag-type machines [10].

3.2. Introduction to wind turbine

The wind turbine incorporates subsystems of the actual turbine, electrical power generation, yaw and control system.

The actual turbine system is the single most important and most costly item of a wind energy conversion system. Although the fuel of the turbine-wind is free, the initial cost is a large contributor to the cost of the energy for the turbine.

There are many aspects of the system that must be considered and carefully optimized before wind energy can be produced at a cost competitive price. These aspects include things like turbine siting, installation and foundations, operating and maintenance costs, manufacturing processes, transport of components to the site, turbine payback period, dependence of wind energy COE on turbine size, and environmental concerns [10]. To minimize the cost, wind turbine must be optically designed for a particular site where the turbine is located.

3.3. Offshore technology

3.3.1. Brief introduction

Offshore wind power technology builds on onshore wind power technology, and it is considered as the key for a dynamic development in the future. Existing offshore wind farms such as Middelgrunden and Horns Rev (in Denmark) have collected first practical experiences [13]. Studies suggest that worldwide offshore wind potential is larger than the electricity consumption [14]. Currently a large number of wind parks are being in the planning and approval procedure.

Compared with normal wind machine, particular requirements related to foundation and connection must be met for the offshore wind farm. Also in planning offshore wind farms several issues regarding environment, acceptance and safety have to be considered [15].

3.3.2. Foundation

Foundation of the wind systems is the most critical technical issue, and much more cost is required than that of the onshore systems. There are several foundation methods including gravity foundation, monopole foundation, tripod foundation and float foundation. Gravity foundation features a flat base. It is stiff but heavy and has a larger footprint compared with the monopole. The maximum water depth for which the solution is suitable is still under discussion; monopole foundation is the most common type for water depths up to 25 m. It has minimal footprint, but on the other hand features low stiffness; Tripod is used for deeper waters. Use of tripod foundation has been made down to 450 m water depth in the oil and gas industry, but there is little experience with wind turbine systems; Floating offshore wind turbine is a candidate mainly in shallow water.

3.3.3. Connection

The connection technique between offshore wind parks and onshore stations is another important issue. Available solutions are HVAC connection and HVDC connection. To select a suitable system, the wind park distance from shore defining the sea-cable length, the water depth and ground properties must be taken into account to evaluate investment cost, transmission loss and cable temperature rise.

4. The current status of wind power in China

4.1. The course of development

Since mid-1980, China began to build wind turbine and wind power plant. However, obvious growth did not appear until 2003 (Fig. 3) [16,17], and this had been triggered by the annual wind power bidding since 2003, which was initiated by the National Development and Reform Commission (NDRC) to speed up the commercialization. The figure shows a really booming growth since 2005, and there is no sign of speed down up to now. The installed wind power capacity reaches 503, 1337, 3304 and 6246 MW from 2005 to 2008, with annual growth of 155.3%, 165.8%, 147.1% and 89.0%, respectively. Only the capacity installed in 2008 has exceeded all those accumulated before, and the capacity in total by the end of 2008 counts for 12.153 GW, much more than the target for the plan in the Eleventh Five-Years (Table 1).

The Renewable Energy Law has played an important role in this rapid growth, which was issued on February 28, 2005 and came into force on January 1, 2006. The grid company is obligated to purchase the wind power and subsidy is guaranteed in framework to reduce the cost.

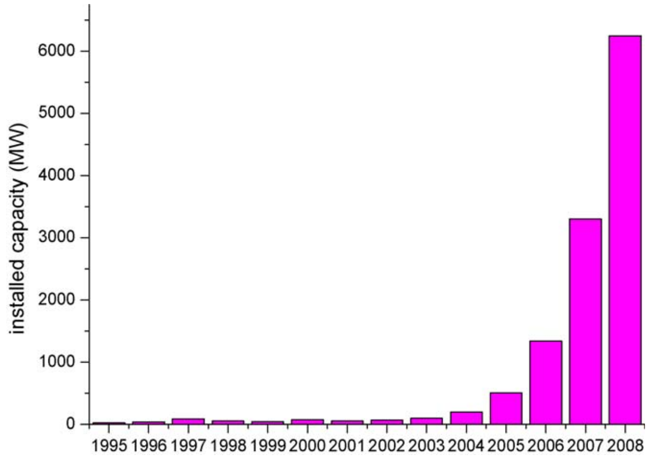

Fig. 3. Annual installed wind power capacity till 2008.

4.2. Wind turbine market in China

4.2.1. Review of wind turbine manufacturer

Wind turbine accounts for 70% in the total investment of the wind power project. Chinese turbine market had been shared mainly by the foreign enterprises. Encouraged by the government policies as well as the bright market future, the domestics companies have developed rapidly. In 2008, the market share of Chinese enterprises (including joint venture) account for 75.6%, for the first time exceeds that of the foreign companies [17]. The Chinese enterprises have mastered the small scale (<1 MW) manufacturing technology, however, the home-made large scale wind turbine is still immature, and need to be improved [18].

The key domestic companies include Gold wind, Dongfang and Sinovel (Dalian), while Gamesa, Vestas and GE occupy important shares in the Chinese market.

4.2.2. Distribution of installed wind turbines

Table 2 lists the wind installed machines in various provinces, and they are distributed in most of all the 34 provinces in China. The machines located in the three-north region (Inner Mongolia, Liaoning, Hebei, Jilin, Heilongjiang, Gansu, Xinjiang, Ningxia) account for 79.07% of the total. Inner Mongolia has far more wind farms compared with the other provinces, and this responds well to the wind resources distribution (Fig. 1). However, there are still large space for the wind farm development in Zhejiang, Shanghai, Shangdong and especially Tianjin (still 0 until 2008), where the wind resources in abundant while the power requirement is the largest in China due to the high economical level.

No offshore wind farm has been installed in China, and a pilot project rated 110 MW is being built in Shanghai, and it is planned to supply power for the World Exposition 2010 Shanghai.

5. Policy and recommendations for large scale deployment

5.1. Policy

Compared with the small scale renewable energy technologies such as small hydropower and solar water heater, wind power especially on-grid is more sophisticated and costly, and the government support is necessary to its development in large scale.

Basic structure has been built from the aspects of organization and legislation. Renewable energy policy, program and planning are consolidated by a certain government apparatus – the NDRC to accelerate utilization of renewable energy; the first comprehensive renewable energy legislation-Renewable Energy Law has been formally approved by the Chinese legislative institution-National People's Congress of China.

NDRC has announced the Mid-Long term Development Plan for Renewable Energy to increase share of the renewable energy in the energy construction to 15% by 2020, and wind power is the highlighted source. It was planned that the total installed capacity should reach 30 GW, and a separate target of 2000 MW was set for the provinces including Inner Mongolia, Guangdong, Fujian, Jiangsu, Shandong, Hebei, Liaoning and Jilin [6]. However, Inner Mongolia has far exceeded this target by the end of 2008 (Table 2). Also six 1000 MW-scale wind farms and offshore wind power accumulated to 1000 MW were also specified in the plan.

The Renewable Energy Law which came into force at the beginning of 2006 provides consistent financial incentives at a national level for renewable energy power generation. The Law requires grid companies to allow interconnection of renewable energy generators and to purchase their electricity at either "fixed" or "guided" prices, to be determined later.

The Law just outlines general principles, and further regulations are necessary to ensure its implementation. Several implementing regulations regarding administrative and pricing provisions have been issued. It is specified that wind power will receive a price based on public tendering; to fund the incremental costs of renewably generated power, a surcharge will be applied to all end users served by the grid, etc.

5.2. Recommendations

5.2.1. Pace for the wind power development

With the strong incentives a booming growth for the wind power installation has come, however, the operation results are not satisfactory. Most of the existing wind farms do not make any profit, because a thorough feasibility study was not carried out for

Table 2
Wind turbines installed countrywide until 2008 [17].

Province	In 2008 installed (MW)	Accumulated (MW)	Province	In 2008 installed (MW)	Accumulated (MW)
Inner Mongolia	2172.25	3735.44	Zhejiang	147.28	194.63
Liaoning	734.45	1249.76	Shanxi	122.5	127.5
Hebei	619.25	1110.7	Yunnan	78.75	78.75
Jilin	457.2	1069.46	Peking	15	64.5
Heilongjiang	428.05	836.3	Hainan	49.5	58.2
Jiangsu	354.5	648.25	Henan	47.25	50.25
Gansu	298.65	636.95	Jiangxi	42	42
Xinjiang	277.5	576.81	Shanghai	15	39.4
Shandong	222.1	572.3	Hubei	0	13.6
Ningxia	38	393.2	Chongqing	1.7	1.7
Guangdong	795	366.89	Hunan	0	1.65
Fujian	46	283.75	Hongkong	0	0.8

the projects. Some wind farm is located far away from the main grid; in some wind farms, the wind resource is not enough to maintain an economical operation, etc.

The locations with abundant wind resources are limited, so the first thing a wind farm company thinking of is to occupy the sites as much as it can. This is one of the main reasons for the above confusion.

The Government should take actions to lower the speed and improve related support systems and regulations. The fundamental requirements should be that the expansion of wind energy use is compatible with the environment and nature, and also economically viable.

5.2.2. Recommendations for offshore wind power

Matched with the enough wind resources, large power load and convenient infrastructure, offshore wind power is well suited for the seashore regions like Shanghai, Shandong and Zhejiang.

Due to its more complex technology, special measures are necessary and also the fundamental requirements same to the onshore wind farm should be followed. Government can learn from the lessons of onshore projects and elaborate a special strategy to control the process. The step-by-step process raised by the German can be used as Ref. [19].

6. Conclusions

Facing the pressure of limited fossil resources and severe environmental issues, the Chinese Government is facilitating the renewable energies. Wind power is good candidate to reduce the share of traditional energy source in the so-called three-north and the eastern littoral regions due to the abundant wind resources. Offshore wind power should be highlighted due to the match of resource and power load distribution.

Inspired by the government policies, an era of rapid growth for wind power has come in China and the target in 2020 seems to be too reserved already. However, actions should be taken to lower the development speed and the current support systems should be re-elaborated to ensure a sustainable and economical development for the wind power.

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